Commentary Articles

Why Life Cycle Impact Assessment is Now Described as an Indicator System

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Abstract

SETAC and ISO now describe the LCIA outcome as LCIA indicators. This contrasts with a SETAC definition of LCIA that is less than five years old. This commentary discusses the two themes that underlie this change in terms and definitions. The first theme is the arrival of a consensus that current LCIA indicators do not describe actual environmental impacts or effects. The second theme is the recognition that some of the ways used to generate indicators results in subjective scores while other ways involve highly simplified assumptions about complex environmental processes. The outcome of the new description is a new emphasis on LCIA transparency. Both the environmental relevance and the scientific basis of each indicator must now be described according to ISO. This increased transparency is essential for decision makers to understand the usefulness of LCIA indicators in making decisions and for audiences to understand what an LCA does or does not say about a product system.

Keywords: Environmental relevance; impact assessment; impact category; indicator; ISO; LCIA; life cycle impact assessment; scientific validity; SETAC subjectivity

1 Introduction

This commentary summarizes recent discussions within SETAC and ISO that have led to significant changes in the description of life cycle impact assessment (LCIA). Both SETAC and ISO now describe the LCIA outcome as *LCIA indicators* (*see* Box 1). This description contrasts with another description that was used only five years ago: '*Impact assessment* in LCA is a technical, quantitative, and/or qualitative process to characterize and assess the effects of the environmental burdens identified in the inventory component' (p. 24, SETAC 1993a). What led to this change in LCA understanding and thinking? First, the development of a general consensus that LCIA cannot provide a characterisation or assessment of environmental effects. Second, a deeper and more detailed understanding of 1) the wide variation in technical capabilities and environmental relevance of a number of LCIA indicators and 2) the subjective, scoring nature of other indictors. Therefore, this commentary focuses on 1) the issue of environmental *effects* and 2) whether and to what degree various LCIA indicators may be the result of a *technical* process.

BOX 1

SETAC No. American LCIA Work Group (SETAC, 1997)
"In the current state-of-the-art, LCIA information about loadings and resource use is in the form of a numerical indicator or index for each category. Important ramifications arise from LCIA being an indicator system, since these indicators are the basis for making comparisons or considering improvement opportunities.

LCIA indicators are approximations and simplifications of aggregated loadings and resources used. Thus, in LCIA, actual impacts are not measured, potential impacts are not predicted, risks are not estimated, and there is no direct linkage to actual impacts.

LCIA indicators vary widely in their reliability and representativeness. Technically, there are significant variations in spatial and temporal scale between LCIA and a number of environmental processes. In addition, there are often differences between simplifying assumptions in LCIA and actual environmental processes. Users should be conscious of these variations and differences in making comparisons."

Summary of SETAC European and No. American LCIA Work Groups (Udo de Haes and Owens, 1998)
"LCIA extrapolates the inventory results as a distillation of inventory loadings and resource use in the form of a category indicator with a numerical category indicator or index result. There is a category indicator for each environmental issue or category. These simplified category indicators are the basis used to make comparisons, considering improvement opportunities, or as potential problems for further investigation."
"LCIA does not represent measuring or predicting actual impacts, predicting potential impacts (in the sense of possible future impacts), estimating risks, or assessing safety."

ISO DIS 14042 (ISO, 1998)
"The LCIA phase uses selected environmental issues, called impact categories, and category indicators to condense and to explain the LCI results. Category indicators are intended to reflect the aggregate emissions or resource use for each impact category."
And in the limitations clause (clause 8)

- "LCIA is, wherever possible, a technical and scientific procedure. However, value-choices are used in the selection of impact categories, indicators, and models, and in grouping, weighting, and other procedures.
- LCIA typically excludes spatial, temporal, threshold and dose-response information and combines emissions or activities over space and/or time. This may diminish the environmental relevance of the indicator result.
- LCIA results do not predict impacts on category endpoints, exceedence of thresholds, safety margins, or risks."

2 Background

There is a rapidly growing interest in environmental indicators. Indicators are seen as a simplified way to distil large bodies of information that typically encompass a multitude of complex issues. For example, the Organization for Economic Co-operation and Development (OECD) provides a pressure-state-response system of environmental indicators (OECD, 1993). The system is intended to give a snapshot summary of each category or issue with three sets of indicators. **Pressure** indicators represent those loadings or pressures on various environmental categories, **state** indicators are then intended to represent the status or condition of the environmental category, and **response** indicators are intended to represent the societal response. Consistent with this concept, an LCA inventory could be condensed to represent a system's pressure indicators from emissions, wastes, and resource use. The LCIA outcome can then be seen as a set of indicators, simplifying and organizing the inventory results based on a multitude of complex environmental issues.

Simultaneously, experience with and understanding of the LCIA phase of LCA has rapidly evolved in SETAC and ISO during the past five years. There is a growing recognition that LCA is crucial to a system-wide and multimedia approach to avoid hidden issues or unrecognized trade-offs (SETAC, 1997; Udo de Haes and Owens, 1998). However experience has also introduced caution in some previous thinking that LCA could be a complete or comprehensive assessment. The current ISO LCIA document (1998b) makes this clear at several points: "Parties should recognise that a complete product system assessment is difficult and may require the use of several different environmental assessment techniques." and "LCIA addresses only the environmental issues that are identified in the goal and scope, therefore, LCIA is not a complete assessment of all environmental issues."

A SETAC LCIA work group (1997) also clarified the same point: "Comprehensive comparisons or the determination of environmental superiority or equivalency using LCIA is not a realistic expectation. First, despite the implicit promise in terms such as 'life-cycle' and 'cradle-to-grave', LCA cannot cover all issues or every part of complex industrial systems. LCA will always be incomplete in some way . . . Second, although LCA contributes the system-wide, multimedia, functional unit approach, it does not address absolute considerations or actual environmental significance. Gaps and omissions in inventory data and lack of resolution and environmental representativeness in LCIA methods are inevitable to some degree now and in the future."

3 Life Cycle Inventory

The life cycle inventory (LCI) phase is the basis for LCIA, and the nature of the LCI process and data will be discussed first. LCI is based on the system inputs and outputs that cross the system boundary. According to ISO (1997), LCI inputs and outputs are materials and energy that enter and leave the system from the environment and to the environment, respectively (ISO, 1997). In addition, the system boundary is typically the interface between a system and the environment, or, in some cases, also the interface with other product systems whose products are the inputs and outputs of the study system and are not elementary flows (ISO, 1997).

The inventory also contains the intrinsic calculations (e.g., a unit process mass balance, co-product and recycle allocation, a functional unit normalization, and typically a system wide aggregation) necessary to understand a system's energy and material efficiencies and to achieve a relative, system-wide approach to interpretation (ISO, 1998a). These ISO definitions and the system view are summarized schematically in **Figure 1** using hypothetical inputs and outputs for examples and directional arrows across the system boundary.

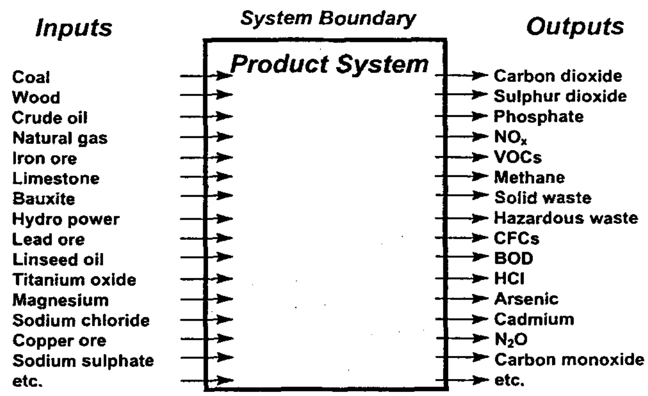

Fig. 1: Schematic representation of life cycle inventory (LCI) with flows across the system boundary of inputs into the product system and outputs from the product system

Importantly, the environment is outside of the studied system boundary. An inventory of materials, emissions, and energy flows crossing a system boundary are then not an analysis of the environment outside of the system or of any *effects* in that environment.

As to the issue of technical process, a properly constructed inventory can indeed be considered a *technical* process, i.e., based on and consistent with transparent, scientific principles and knowledge . Parties must recognized that 1) numerous judgements and choices about function, boundaries, inclusion and exclusion are made in applying the technical process and 2) these judgements and choices must be transparent and justified in a study report.

4 LCIA Classification

The LCIA process begins with the classification step, i.e., organizing of the LCI results along environmental issues or categories (ISO, 1998b). The LCI results are assigned to se-

lected impact categories that represent specific environmental issues for a study (ISO, 1998b). Based on this organization exercise, the indicators or results will then be modelled for each category to reflect the aggregate emissions or resource use for each impact category (ISO, 1998b).

The effective outcome of LCIA classification is that the inputs and outputs are rearranged and organized into specific collections of resources, waste and emissions issues, e.g., impact categories. The outcome of classification is summarized schematically in **Figure 2** so that the reader can observe 1) the intrinsic similarity with Figure 1 and 2) the environmental perspective into which the inventory is now organized. However, the classification step remains a view of materials, emissions, and energy flows crossing a system boundary. Again, LCIA at this stage is not an analysis of the environment outside of the system or of environmental *effect*.

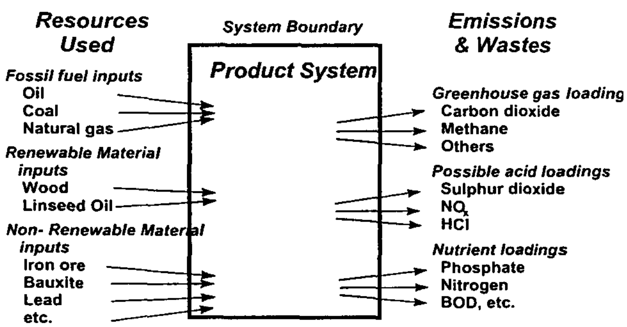

Fig. 2: Schematic representation of life cycle inventory (LCI) results, still as input and output flows across the system boundary, but now assigned and organized into particular categories

The question then at this stage is: Is classification a *technical* process? The answer is: not consistently. Often the organization of the inventory inputs and outputs into impact categories is not based on scientifically and technically valid principles. The central concept for scientifically valid categories began at the SETAC Sandestin workshop where each impact category would be based upon a common or homogenous mechanism or mode of action (SETAC, 1993b). The guiding principle in the case of a homogenous environmental mechanism is that the resources and emissions assigned to an impact category are then assumed to have a sound, mechanistic basis to combine and act together in the environment. This would support that the assignment together in the impact category is valid. Otherwise, without a mechanistic basis, the assignment depends to some degree upon subjectivity or other assumptions so that the outcome will be a score (Owens, 1998).

A clear example of subjective classification is noted by ILSI. The combination of different types of toxicity into a single impact category, such as reproduction, cancer, liver, and kidney effects, is a scoring or valuation process: "It is inherently impossible to make a purely scientific comparison of qualitatively or quantitatively different toxicity impacts. This type of aggregation is equivalent to comparing the impacts of global warming and acid rain. Such a comparisons cannot be done scientifically." (ILSI, 1996).

Thus, for a number of categories, LCIA is not a *technical* process (SETAC, 1997; Udo de Haes and Owens, 1988, and Ilsi, 1996). As a result of this new understanding, SETAC and ISO (ISO refers to subjectivity as 'value-choices') recommend that subjectivity be made transparent and that any environmental mechanism for an impact category be clearly described (SETAC, 1997; ISO, 1998b). Recognizing that different parties have different values and will score in different ways, ISO requires that only scientifically and technically valid indicators can be used for comparative assertions (ISO, 1998b).

There are additional technical issues for an impact category even when an environmental mechanism, the network of physical, chemical, and biological processes linking LCI results to category indicators and category endpoints, exists. These issues affect the quality of the LCIA information that will be used for making comparisons and decisions. It is now recognized that a very wide variation in the technical ability of different category groupings exists for efforts to represent the interaction of a system with the environment (SETAC, 1997; Udo de Haes and Owens, 1998; ISO, 1998b). This will also lead to differences in the environmental relevance of the indicator.

Even when an environmental mechanism may exist, both SETAC and ISO have recognized that the inventory procedures and classification face issues, particularly the aggregation inputs and outputs from different places and times (SETAC, 1997; Udo de Haes and Owens, 1998; ISO, 1998b). This type of aggregation implicitly assumes a simultaneous action or exposure of different compounds. However, in cases like eutrophication, only one limiting nutrient exists at a site, and combination of phosphorus and nitrogen is not technically valid at the same site. There are other difficult questions about the aggregation of different eutrophication responses from different sites and times regardless of the nutrient involved.

A second inherent technical complication is now recognized and better understood: a set of impact categories will have different combinations of spatial and temporal scales (SETAC, 1997; Udo de Haes and Owens, 1998; ISO, 1998b). The inventory phase is then confronted with added complexity of collecting and maintaining the input and output data where they can be related to the different spatial and temporal scales of different environmental processes in the LCIA phase. The spatial scales for different categories may be summarized as global, continental, regional, and local, and the temporal scales may be summarized in different time frames of centuries, years, months, days, and even hours. Useful illustrations of differences in scales are acidification and photochemical smog. Acidification emissions are local and have a limited

temporal scale, acids deposition is continental to regional and is usually addressed on an annual basis, and environmental effects are regional and their time frames are typically considered on a basis of at least several years. Photochemical smog emissions (both volatile organic compounds and nitrogen oxides) and their resulting production of ozone are local, transient events. The effects are typically local and transient for human health, but for plant species may be local or regional in spatial scale and may be seasonal for annual crops or several years for forests.

5 LCIA Characterization

The next step in the LCIA process is characterization, which is composed of two core procedures. First, each of the input and output LCI results are converted using a characterisation factor, preferably using a model based on an environmental mechanism for that impact category (ISO, 1998b). Second, the converted LCI results are then aggregated or added together into the category indicator (ISO, 1998b).

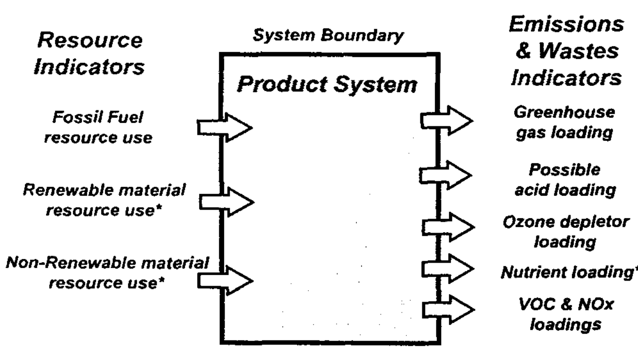

Fig. 3: Schematic representation of life cycle inventory (LCI) results after characterization. The results are now presented as calculated indicators for certain categories. Note, however, that these indicators are still emission and resource flows across the system boundary

Characterisation in its simplest form begins with the common chemical properties of the emissions for each category. An example is acidification where the inventory emissions are converted into proton equivalents. Characterisation may become more detailed when the properties such as fate and transport are incorporated. Again, however, this is not yet an analysis of the environment outside the system or of any consequences or *effects* that may occur there. In this regard, promising efforts to address spatial issues for some impact categories such as acidification are underway (POTTING et al., 1998).

The question for characterisation is: What is *technical* validity and quality of the two procedures after classification, i.e., the conversion of the LCI results and the aggregation of these converted results into the indicator?

For the first procedure or the conversion of LCI results, recall that the SETAC Sandestin workshop noted that LCIA uses two assumptions: 1) a linear relationship exists between the LCI results and the LCIA indicators and 2) no environmental threshold exists for LCIA indicators (SETAC, 1993b). As these assumptions can severely limit the environmental realism and relevance of the indicators, it is useful to examine the origin of these assumptions more closely. The origins lie in the mathematical basis or formula for most current characterization calculations. The examination makes the assumptions clear as well as the impact on the technical validity and relevance of the indicator and the usefulness of indicator information quality for decision makers. The basic formula is:

Converted LCI result =
Characterization factor for the LCI result • LCI result

In algebraic terms, this formula appears more simply as:

$$y = a \bullet x$$

When graphically plotted as shown in **Figure 4**, this formula is clearly 1) a linear equation and 2) has a zero intercept! Respectively, this means in terms of environmental information that 1) a linear relationship must exist between the LCI results and the indicator and 2) the indicator will have a zero intercept with no consideration of any threshold.

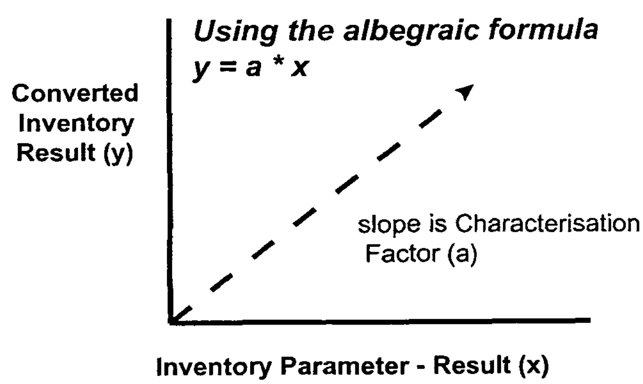

Fig. 4: Graph of simple mathematical application of a characterization factor to a LCI result showing the linear nature and non-threshold zero-intercept of this formula is the basis for these assumptions in LCIA

Indicators generated in this manner are then truly simplified estimates of emissions, waste, and resource use. The next question is whether subjective scores are absent in arriving at the characterization factor or the basis for conversion. If not absent, the technical estimates of some indicators will need to be transparently distinguished from the other indicators where subjective scoring occurs.

For the second aggregation procedure, there are technical limitations similar to those discussed above. Aggregating the

converted LCI results into an indicator faces the same issues about the quality and the usefulness of indicator information for decision makers. Examples are 1) the presumption of a common, joint action and 2) the presumption simultaneous exposure even though the emissions are aggregated together across a system from different places and times. These spatial and temporal aggregation issues then question 1) how well the indicator may represent the environmental issues of concern and 2) what environmental relevance the indicator may have for any environmental consequences beyond the system boundary. In a larger context, this calls into question the actual environmental usefulness of comparisons made using LCIA indicators in their present form.

6 Discussion

Currently, LCIA is indeed an indicator system. LCIA is a simplified way to condense and to examine the LCI inventory as emissions, wastes, and resources and to use the inventory data in an environmental context. As shown in **Figures 1, 2, and 3**, the inventory results are generated, classified, and modelled into an indicator, respectively. LCIA is then fundamentally an analysis of system inputs and outputs leaving and entering the environment and not an analysis of the environmental consequences or effects from a system. Both SETAC and ISO now clearly state that the LCIA indicators are not measuring or predicting actual *effects*, predicting potential *effects*, or estimating risks (SETAC, 1997; UDO DE HAES and OWENS, 1998; ISO, 1998b).

The *technical* issues involved in LCIA classification and characterisation are also increasingly recognised, e.g., spatial and temporal issues, subjectivity, aggregation issues, etc. The LCIA depiction of the inventory flows encounters these issues in the three basic LCIA operations that produce the LCIA indicator: 1) organizing the inventory parameters in categories, 2) converting the LCI results with characterization factors, and 3) aggregating the converted LCI results into indicators. For example, indicators may result from subjective grouping into impact categories or highly simplified characterization models of only the chemical properties of the emissions such as proton equivalents. There are also the difficulties in dealing with increasingly complex spatial, temporal, dose-response, and threshold issues as well as site to site variations.

These subjective judgments and technical issues are the source of concerns for 1) scientific and technical validity of the indicators (SETAC, 1997; ISO, 1998b) and 2) the environmental representativeness or relevance of the indicators (SETAC, 1997; ISO, 1998b). The ISO 14042 document provides a series of criteria for environmental relevance and notes the wide variation among different indicators, providing guidance and cautions that:

1. The usefulness of the information from indicator results depends on the accuracy, validity, and characteristics of the models and characterisation factors;
2. The usefulness of the information from indicator results also depends on the number and kind of simplifying assumptions and value choices used in the model for the indicator. This will also vary among impact categories as trade-offs often exist between model simplicity and accuracy, and
3. The quality of indicator information among different impact categories varies for a number of reasons such as the complexity of environmental mechanisms between the system boundary and the category endpoint, the spatial and temporal characteristics of the category, and the dose response characteristics (ISO, 1998b).

This has important implications for the users of LCA in making decisions.

1. The information provided by LCA for their decisions is not about environmental effects; it is a relative view about the emissions and resource use for a system;
2. The information may not always be technical. Instead, subjective classification and characterisation may result in scores; and
3. The technical quality and usefulness of the information from different indicators varies considerably.

As noted by SETAC: "Users must be aware that LCIA indicators vary widely in how well they do or do not connect with different environmental themes or processes. Technically, a wide range of disparities in spatial and temporal scales as well as mechanistic considerations, e.g., thresholds, exist between LCIA and a number of environmental processes. (UDO DE HAES and OWENS, 1998)." Thus, it is technically logical and transparently communicated to users to describe the LCIA as indicators.

Both SETAC and ISO suggest that LCA should not be the sole means used to make comparisons. Rather, parties should combine the information derived with LCA with information derived other techniques, other information sources, and approaches to arrive at sound decisions. For example, decisions should benefit from information resulting from a combination of *both* the relative LCA approach and the absolute approaches of other techniques, such as environmental fate modelling, environmental monitoring, environmental impact assessment, and risk assessment. The system-wide, relative LCA approach can be seen to identify and analyse possible system issues and trade-offs, where absolute tools would analyse in detail the issues raised by LCA. These different information contributions would then be combined in making the decision.

In the past five years, SETAC and ISO have been recognized and clarified a number of major LCIA issues. The advances are 1) a new description of LCIA results as indicators, 2) a better understanding of the value and quality of information in these indicators, and 3) a renewed call and new rationale for transparency in LCA studies. Users and audiences may now understand the true nature of each LCIA indicator in making their decisions. They can arrive at im-

proved decisions that can be explained and justified both internal to their organizations and externally to other organizations and the public.

Importantly, these SETAC and ISO clarifications should help make LCA a more credible environmental technique. For example, LCA will not be misrepresented as analyzing environmental *effects*, and the different technical difficulties will be more transparent to decision makers and other audiences. This should reduce the number of disputes over LCA interpretation and place behind us some of the debates of the last few years. At the same time, we should also recognize that both ISO and SETAC have reemphasized the core benefits of LCA that were never in dispute: 1) quantifying material and energy efficiency for a system, 2) identifying improvement opportunities and trade-offs, 3) illuminating hidden or unrecognized issues, and 4) promoting a wider and more rational communication among stakeholders about how to compare and improve highly complex and difficult to analyze industrial systems.

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SETAC-Europe: Second Working Group on LCIA (WIA-2)
Best Available Practice Regarding Impact Categories and Category Indicators in Life Cycle Impact Assessment

Background Document for the Second Working Group on Life Cycle Impact Assessment of SETAC-Europe (WIA-2)

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